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The Strong Porter Hypothesis in an Endogenous Growth Model with Satisficing Managers

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Abstract

Few endogenous growth models have focused attention on the strong Porter hypothesis that stricter environmental policies induce innovations, the benefits of which exceed the costs. A key assumption underlying this hypothesis is that policy strictness pushes firms to overcome some obstacles to profit maximization. This paper incorporates pollution and taxation in the model of Aghion and Griffith (2005) of growth which includes satisficing managers and non-drastic innovation. Our theoretical results predict the strong Porter hypothesis. However, assuming drastic innovation in the model, we predict the weak Porter hypothesis. We also consider several extensions, such as a simultaneous competition policy or a command and control policy.

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1. Introduction

In his engaging 1990's paper "America's green strategy", Michael Porter provided case studies to support the argument that the stricter a country's environmental policy, the more its firms innovate in a profitable way to produce less polluting or more resource-efficient products; see Porter (1996). Porter and van der Linde (1995) present further firm-level evidence and put forward that the above argument holds true in a world where firms do not always make optimal choices, due, e.g., to organizational inertia and control problems. Otherwise, complying with a stricter environmental policy could never be profitable. Jaffe and Palmer (1997) called that argument the *strong Porter hypothesis*, which they distinguished from a *weak* hypothesis whereby "the additional innovation [comes] at an opportunity cost that exceeds its benefits" for firms. They also identified a *narrow* version, which makes no consideration about profits and favors direct regulation (e.g., standards and output ceilings) when pollution requires immediate action.

There have been attempts in endogenous growth theory to model the strong Porter hypothesis as a channel of transmission of stricter environmental policy to growth. A few of those attempts focus attention on the importance of the assumption of profit maximization for this hypothesis. Ricci (2007a) recommends researchers "[not to drop] the assumption of rationality", that is, the profit maximization model, under informational constraints on the part of firms' owners. Jaffe, Newell, and Stavins (2002), in contrast, assert that replacing profit maximization with non-optimizing behavior creates possible improvements in profits. Ambec and Barla (2007) suggest to use the Aghion, Dewatripont and Rey's (1997) framework with intermediate firms in which managers' decisions about innovation are better considered as *satisficing* rather than profit-maximizing. As far as we are aware of this strand of the endogenous growth literature, its authors subscribe to the former approach. They assume that firms pursue profit maximization in all markets.[1]

This paper contributes to the debate on the importance of assuming profit maximizing firms in models of the strong Porter hypothesis. We relax this assumption regarding the decisions of managers on innovation. We use the R&D-driven endogenous growth framework of Aghion and Griffith (2005), which we extend to allow for pollution and environmental taxation. Innovation is undertaken in the intermediate sector. We impose regulation in the final good sector as in Nakada's (2004) endogenous growth model. This assumption is consistent with Porter and van der Linde's (1995) suggestion that governments should "regulate as late in the production chain as practical, which will normally allow more flexibility for innovation there and in the upstream stages." (p. 111).[2] Aghion and Griffith's (2005) model is a special case of the vintage capital model of Aghion, Dewatripont, and Rey (1997) in which owners incur a high fixed cost of production/innovation which they internally finance. In this latter model, which provides micro foundations for satisficing behavior in endogenous growth theory, managers who discount future benefits and costs choose a size of innovation just high enough to avoid bankruptcy and hence preserve their private benefit of control.

Previous endogenous growth models on Porter hypothesis are based on profit maximizing behavior. They include Nakada (2004) who allows for pollution and a resource constraint on R&D activities in a framework *à la* Aghion and Howitt (1992). He finds

[1] The microeconomic literature on Porter hypotheses includes various behavioral models of the firm; see Ambec, Cohen, Elgie, and Lanoie (2013) for a survey on these models. Other market imperfections are also covered in Mohr and Saha (2008) and André (2015).

[2] Porter and van der Linde (1995) who have a preference for market-based regulation pose the question of where to impose environmental regulation in the chain of production.

that the "general equilibrium effect" of an increase in the environmental tax rate offsets the "profitability effect" in the intermediate inputs sector. In the long-term, environmental taxation enhances growth and reduces the level of pollution. We calculated the long-term effect of an increase in the tax rate on downstream firms' profits in Nakada's (2004) model. This effect is positive, thus verifying the strong Porter hypothesis.

Mohr (2002) finds results consistent with the narrow Porter hypothesis in a vintage capital framework with positive spillovers in production, new technologies which are more productive and cleaner than the old technologies, and producers who have a cost to switch to these latter. At any period every firm can behave selfishly by letting the others bear the switching cost. Under certain conditions, a stricter environmental policy (a technology standard whereby all firms must switch to the new technology) alleviates pollution and increases output. There is a risk in Mohr's (2002) model, however, that a benevolent planner finds profitable to let pollution be higher as technology improves. In Hart's (2004) model, environmental regulation consists in favouring recent vintages too. His results are consistent with the narrow version of Porter hypothesis.

Ricci (2007b) extends the multi-period frameworks of Hart (2004, 2007) by taking into account flexibility in the technological choice of R&D firms. He analyzes the possibility that environmental taxation, instead of standards, crowds out old and dirty intermediates inputs. Unlike in Hart (2004, 2007), productivity growth is negatively affected in Ricci's (2007b) model. Among non-endogenous growth models taking up the strong Porter hypothesis without departing from the maximization model, there is Xepapadeas and de Zeeuw (1999) who analyze the effect of environmental policy on capital accumulation. These authors eventually predict the weak Porter hypothesis: although an emission tax increases average productivity by stimulating the retirement of older vintage capital, the profits of taxed firms decrease. Feichtinger, Hartl, Kort, and Veliov (2005), who extend Xepapadeas and de Zeeuw (1999) to allow for nonlinear functional forms and technological change, do not find the strong Porter hypothesis either in their model.

The rest of the paper is structured as follows.

In section 2 we extend the Aghion and Griffith's (2005) model to allow for pollution and environmental taxation. Section 3 focuses on the effects of an increase in the environmental tax rate (a stricter environmental policy) on innovation, pollution, growth and downstream profit. This change in environmental policy plays the same role as an increase in potential competition in Aghion and Griffith's (2005) model: it makes the survival constraint of intermediate firms tighter; satisficing managers, who fear to loose their job, respond by increasing the size of innovation, which, in return, raises the quality of intermediate inputs and reduces pollution. Furthermore, the higher tax rate increases economic growth and downstream firm's profit, thus verifying the strong Porter hypothesis. Section 4 discusses several changes to the model's assumptions and a few extensions. For instance, we assume that innovation is drastic, that is, in each intermediate market, innovation is large enough that the incumbent monopoly can charge a price above the marginal cost of the fringe. We also replace the market-based policy with a command and control policy. The main extension adds competition policy. Section 5 concludes with suggestions about possible extensions regarding the assumption of profit-maximization in the model.

2. The model

We use the R&D-driven endogenous growth model of Aghion and Griffith (2005) with satisficing managers, which we extend to allow for pollution and environmental taxation of producers in the final good market. In Aghion and Griffith's (2005) model, the growth rate of the economy is an increasing function of the satisficing size of innovation, which itself is determined by intermediate firms exploiting their market power against final good producers and blocking entry of a less cost-effective fringe. Their two-period discrete model is a simplified version of the Aghion, Dewatripont, and Rey (1997) analysis of the relationship between competition, industrial policy and growth for two types of intermediate firms. Firms in which managers' decisions regarding the size of innovation is to maximize profits, and firms in which managers maximize their private benefits net of innovation efforts. We consider only the second type of firms whose managers are called "satisficing managers" throughout the rest of the text.

2.1 The competitive final good sector. One final *numéraire* good y_t is produced competitively in period t according to the constant returns to scale production function

$$y_t = \int_0^1 A_t(i)^{1-\alpha} x_t(i)^\alpha di, \quad 0 < \alpha < 1, \tag{1}$$

where the productivity parameter $A_t(i)$ also measures the quality of the flow of intermediate input i, $x_t(i)$, at time t.

We follow Nakada (2004) who assumes that pollution arises from the use of the x's in production of y. An environmental technology index $z_t(i)$ relates the quantities of intermediate inputs to pollution. Unlike in Nakada (2004), however, $z_t(i)$ is endogenous; it is inversely proportional to $A_t(i)$, that is, $z_t(i) \equiv 1/A_t(i)$.[3] The structural pollution equation in each intermediate market i is therefore

$$z_t(i)x_t(i) = \frac{x_t(i)}{A_t(i)} \equiv P_t(i). \tag{2}$$

Equation (2) is consistent with the argument of Nakada (2004) that the higher the index (the lower the quality of i), the higher the level of pollution per unit of intermediate input (Ricci, 2007a, p. 696 defines this ratio as pollution intensity).[4] Environmental policy takes the form of a unique unit tax τ_t. The tax, which varies directly as $P_t(i)$, is paid by the downstream firm to discourage pollution.[5] This assumption is different, e.g., from that of Hart (2004) who applies the unit tax to output. Let the price of the ith intermediate input be $p_t(i)$. The representative downstream firm's profit $\pi_t(y)$ is:

$$y_t - \int_0^1 p_t(i)x_t(i)di - \tau_t \int_0^1 P_t(i)di. \tag{3}$$

For each intermediate input i, downstream firms maximize (3), given the technology in (1), up to the point where marginal productivity $\alpha(x_t(i)/A_t(i))^{\alpha-1}$ equals tax-inclusive marginal cost $p_t(i) + \tau_t(i)/A_t(i)$. The solution leads to the following inverse demand,

$$p_t(i) = \alpha(x_t(i)/A_t(i))^{\alpha-1} - \frac{\tau_t}{A_t(i)}. \tag{4}$$

[3] In section 4 we consider the less restrictive assumption of imperfect negative correlation between z and A ($z_t(i) \equiv 1/A_t(i)^\beta$).

[4] Notice in equation (2) that there are no spillovers between markets.

[5] The average tax per unit of input $\tau_t P_t(i)/x_t(i) = \tau_t z_t(i)$ also varies directly as pollution intensity.

We see that the unit tax on pollution shifts downward the demand schedule for the intermediate good. We now turn to incumbent firms' decisions in the intermediate sector.

2.2 The decisions of monopolistically competitive intermediate firms. Incumbent firms make two related decisions: the quantity of x to sell to final good producers (regardless the degree to which this amount will degrade the environment), and their managers decide on the size of innovation, which will be defined later. Incumbents produce x from y according to the identity technology at a marginal cost of 1. In each intermediate market i, a fringe could produce the same good at a higher marginal cost (of imitation) $\chi > 1$. Innovation is non-drastic ($\alpha^{-1} > \chi$).[6] Incumbents exert their market power by charging the limit price $p_t(i) = \chi$ so as to prevent the fringe from entering their market. Setting equation (4) equal to χ, the equilibrium sales for intermediate input i is

$$x_t(i) = \alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}} A_t(i). \tag{5}$$

Inserting equation (5) in equation (2), pollution is equal to:

$$P_t(i) = \alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}}, \tag{6}$$

which decreases with environmental regulation stringency ($\partial P_t(i)/\partial \tau_t < 0$), holding $A_t(i)$ and all parameters constant.

Intermediate firms are self-financed. In addition to a unit marginal cost they incur a fixed cost of production $\kappa A_{t-1}(i)$ at the beginning of period t. κ is sufficiently large to allow for bankruptcy ($\kappa > \chi - 1$), in which case, managers would lose their job. Managers live for one period. The value for profit net of the fixed cost of production in period t is $\pi_t(i) = (p_t(i) - 1)x_t(i) - \kappa A_{t-1}(i)$. Under the previous assumption that intermediate incumbents opt for limit pricing, and using equation (5), $\pi_t(i)$ can be rewritten as:

$$\pi_t(i) = (\chi - 1)\alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}} A_t(i) - \kappa A_{t-1}(i). \tag{7}$$

Let us denote the size of innovation in intermediate market i by $\gamma(i)$. Each time an intermediate firm i innovates, its productivity increases by the factor $\gamma(i)$:

$$A_t(i) = \gamma(i) A_{t-1}(i). \tag{8}$$

Inserting equation (8) in equation (7), one obtains:

$$\pi_t(i) = [(\chi - 1)\alpha^{\frac{1}{1-\alpha}} \left(\chi + \frac{\tau_t}{\gamma(i)A_{t-1}(i)}\right)^{\frac{1}{\alpha-1}} \gamma(i) - \kappa] A_{t-1}(i), \ \forall\ 0 \leq i \leq 1. \tag{9}$$

Unlike the Aghion and Griffith's (2005, p. 38) model, in which there is no pollution and no environmental regulation, intermediate profits $\pi_t(i)$ are nonlinear in $\gamma(i)$ for all i; thus, finding a solution which corresponds to managers' decisions on the size of innovation is different than in their model where the $\gamma(i)$'s are equal across intermediate markets.

[6] α^{-1} is the monopoly price incumbent intermediate firms would charge were environmental regulation absent. Under regulation, the price is equal to $\alpha^{-1} + \alpha^{-1}(1-\alpha)\tau_t/A_t(i)$, which is greater than α^{-1}.

2.3 Satisficing managers and the size of innovation. Porter and van der Linde (1995) suggest organizational inertia and lack of control over managers among the possible constraints that firms will have to shift to comply with environmental policy. Interestingly, Aghion and Griffith (2005) assume intermediate firms subject to organizational slack in their framework, although they do not formalize slack as explicitly as in Aghion, Dewatripont, and Rey (1999). Relying on the works of Nohria and Gulati (1996) and Aghion, Dewatripont, and Rey (1997, 1999), we define *slack* as under-exploited managerial resources to increase innovation, in the sense that managers enjoy private benefits (net of innovation efforts) greater than the amount required to retain them within the firm.

This definition of "slack" has a quantitative counterpart. Let us denote the private benefit a manager gets from controlling the intermediate firm by B. And, let $B-\gamma$ denote this benefit net of innovation efforts. The difference $B-\gamma$ is a simple version of managers' objective function in Aghion, Dewatripont, and Rey (1999). However, Aghion and Griffith (2005) do not not include B in their model; they consider a straightforward solution for γ that results from setting equation (9) equal to 0.[7] Managers, who fear to loose their job, are mainly concerned with preserving a positive net benefit of control in intermediate firms; thus, as long as $B>\gamma$, there is some room to reduce slack. We model the decision of satisficing managers on the size of innovation by solving the classical programming problem $\max_\gamma\{B-\gamma : \pi \geq 0\}$. The implicit solution of this problem, γ^{ND} ('ND' stands for 'non-drastic' innovation), is highlighted in Figure 1.

For abscissae we have γ. For ordinates, we have the values of an intermediate firm's profit π (equation (9)) and of manager's benefit net of innovation efforts $B-\gamma$ which is represented by the line with slope -1. γ^{ND} is the point at which the profit function π (the thick curve) crosses the horizontal axis (see the first part of Proposition 1 in Appendix A). If managers choose a size $\gamma < \gamma^{ND}$, then their net benefit of control increases but the firm goes bankrupt ($\pi < 0$). Whereas, if $\gamma > \gamma^{ND}$, owners' profit increases at the expense of managers. The difference $B-\gamma^{ND}$ may be defined as a measure of organizational slack at point γ^{ND}. If there were no organizational slack and if managers had an outside option that yields a net benefit of zero, then B would be the maximum innovation effort and $[(\chi-1)\alpha^{\frac{1}{1-\alpha}}\,(\chi+\tau_t/BA_{t-1}(i))^{\frac{1}{\alpha-1}}\,B-\kappa]A_{t-1}(i) \equiv \bar{\pi}(i)$ would be the maximum profit firm i's owners could obtain. We reported this point on the vertical axis. The following section focuses on the effect of an increase in the tax rate on the size of innovation, pollution, growth and profit in the downstream sector.

[7] Aghion and Griffith (2005) assume B is sufficiently large that it can be ignored and write managers' program as a minimization of $\gamma : \pi = 0$. Since there is no environmental regulation in their model they obtain the simple solution $\frac{\kappa}{(\chi-1)\left(\frac{\chi}{\alpha}\right)^{\frac{1}{\alpha-1}}}$, which is identical across markets.

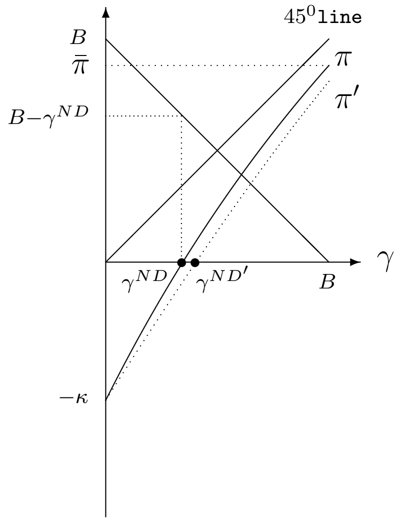

Figure 1. Satisficing size of innovation before the tax increase (γ^{ND}) and after ($\gamma^{ND'}$).

3. Effect of a stricter environmental policy

Predicting the strong Porter hypothesis in our model requires finding that a stricter environmental policy, that is, a higher τ_t, increases the size of innovation ($\partial\gamma^{ND}/\partial\tau_t > 0$), reduces pollution ($\partial P_t/\partial\tau_t < 0$), enhances growth $(y_t - y_{t-1})/y_{t-1} > 0$ and benefits firms. This latter condition only needs to be verified in the downstream sector since profits in intermediate firms are set equal to zero by satisficing managers. Proposition 1 below states that our model verifies these conditions.

Proposition 1. *If innovation is non-drastic ($\alpha^{-1} > \chi$), for $\kappa < B$ sufficiently large, a higher environmental tax rate:*

(i) *increases the size of innovation;*
(ii) *reduces pollution;*
(iii) *enhances growth;*
(iv) *increases downstream firm's profit.*

Proof. *See Appendix A.*

We focus on the impact of a higher tax rate on downstream profit by decomposing this impact into direct and indirect effects.

From equation (3) a higher τ_t increases $\tau_t P_t(i)$ for all i, which has a direct negative effect on downstream profit. The downstream sector responds by reducing its demand for intermediate inputs, which can be seen from equation (4). This shift in demand implies a fall in output y_t but also lower production costs in the downstream sector ($\int px$ decreases in equation (3)). It also reduces monopoly rents $(\chi - 1)x_t$ of incumbent intermediate firms whose profits become negative (equation (7)).

Satisficing managers respond by increasing the size of innovation just high enough to avoid bankruptcy ($\pi_t(i)$ in equation (9) is set equal to zero). The dotted curve π' which lies below π in Figure 1, represents profits after an increase in τ_t. The value for π' would be negative at point γ^{ND}; thus, the new size of innovation $\gamma^{ND'}$ is necessarily greater than γ^{ND} and slack decreases to $B - \gamma^{ND'}$. Consequently, productivity $A_{t-1}(i)$ increases from $\gamma^{ND}A_{t-1}(i)$ to $\gamma^{ND'}A_{t-1}(i)$ (equation (8)).

This increase in productivity has a positive effect on output, which is reinforced through the response of downstream demand in equation (5); x is indeed a positive function of A in that equation. On the other hand, the higher size of innovation decreases aggregated pollution $P_t = \int_0^1 P_t(i)di$ ($\frac{\partial P_t}{\partial \tau_t} = \frac{\kappa}{\chi - 1} \int \frac{\partial}{\partial \tau_t}(\frac{1}{\gamma}) < 0$), although insufficiently to compensate for the direct effect of a higher tax rate ($\frac{\kappa}{\chi-1} \int \frac{1}{\gamma} > 0$);[8] i.e., $\tau_t P_t$ increases in equation (3). Overall, the positive effect on output compensates for the negative effect of the tax increase; we have $\frac{\partial y_t}{\partial \tau_t} = \frac{1}{\alpha} \frac{\kappa}{\chi-1} \int \frac{\partial}{\partial \tau_t}(\frac{\tau_t}{\gamma}) > 0$ and downstream profit increases, $\frac{\partial \pi_t(y)}{\partial \tau_t} = (\frac{1-\alpha}{\alpha})(\frac{\kappa}{\chi-1}) \int \frac{\partial}{\partial \tau_t}(\frac{\tau_t}{\gamma}) > 0$.

To check the robustness of Proposition 1, we considered several changes to the model's assumptions and few extensions: drastic innovation, vertical integration, different regulations and some opportunity cost in R&D when targeting cleaner innovations. We also offer some discussion about how competition policy interferes with the win-win environmental policy.[9]

4. Extensions: how robust is the strong Porter hypothesis?

Making the opposite assumption that innovation is drastic (the direction of the inequality $\alpha^{-1} > \chi$ changes to $\alpha^{-1} < \chi$), the strong Porter hypothesis no longer holds in this model (only parts *i* to *iii* of Proposition 1 are verified). As shown in Appendix B, we need additional constraints on the parameter set to maintain incumbent prices $p_t(i)$ below the marginal cost of the fringe, χ. Under these assumptions, part *iv* is not verified because downstream profit, $\frac{\kappa}{\alpha} \int_0^1 A_{t-1}(i)$, although higher than that when innovation is not drastic, no longer depends on τ_t. Any extra rent from further innovation following the tax increase is fully appropriated by intermediate incumbents. And, none of this extra rent is transferred to owners of intermediate firms in which satisficing managers increase innovation just enough to maintain economic profit to zero. The lack of effect on downstream profit is evidence of the weak Porter hypothesis. Noteworthily, this result is also a consequence of the change in the behavior of managers who maximize the monopoly rent with respect to x. Thus, complying with a more stringent environmental policy is not profitable when innovation is drastic so that incumbent's pricing is that of a pure monopoly.

Considering vertically integrated firms provides another interesting insight regarding the effect that market structure has on our results; see appendix C.1. Assume that in each intermediate market i, the vertically integrated firm maximizes the sum of downstream profit $A_t(i)^{1-\alpha} x_t(i)^\alpha - p_t(i)x_t(i) - \tau_t P_t(i)$ and intermediate incumbent's rent $(p_t(i) - 1)x_t(i)$; we consider the cost of production/innovation $\kappa A_{t-1}(i)$ later when deriving the satisficing size of innovation. We find that the size of the innovation is smaller than that under vertical separation, which can be seen using the first part of Proposition 1 applied to the implicit function under vertical integration $h^{VI}(\tau_t, \gamma)$. It can be shown that $h^{VI}(\tau_t, \gamma) > h(\tau_t, \gamma)$ for all γ, where $h(\tau_t, \gamma)$ which we defined in Appendix A is the implicit function under vertical separation. $h(\tau_t, \gamma^{ND}) = 0$ from Proposition 1, which implies that $h^{VI}(\tau_t, \gamma^{ND}) > 0$. But, h and h^{VI} are increasing in γ. Consequently, γ^{VI}, which solves the implicit equation $h^{VI}(\tau_t, \gamma) = 0$ is less than γ^{ND}.

We also checked whether our results are valid for a different kind of regulation (Appendix C.2) and when intermediate firms pay the tax (Appendix C.3). In these cases,

[8] Using the zero-profit condition $(\chi - 1)x_t(i) - \kappa A_{t-1}(i) = 0$ and equation (8), we obtain $P_t(i) = \frac{K}{\chi-1}\frac{1}{\gamma(i)}$.

[9] We thank the referees for having invited us to investigate these extensions. We address the case of drastic innovation in section 4 and appendix B of the paper. Proofs regarding the other extensions are available in on-line appendix C.

the model is more tractable. First, considering a limit on the amount of pollution for each input ($P_t(i) \leq \bar{P}$) leads to two solutions according to whether $\bar{P}$ is greater or less than some threshold $\mu \equiv (\chi/\alpha)^{\frac{1}{\alpha-1}}$. When the constraint is binding ($P = \bar{P}$), we find solution $\bar{\gamma} = \frac{\kappa}{(\chi-1)\bar{P}}$, which is constant across markets. Economic growth simply equals $\bar{\gamma} - 1$ which is greater than 0 and increases with stricter regulation ($\bar{P}$ decreases). Part *iv* of Proposition 1 is also verified. These results are slightly different if we consider a limit on the input-emission ratio ($z_t(i) \leq \bar{z}$; see, e.g., Verdier (1995)): parts *i*, *iii* and *iv* are verified, whereas pollution is not affected by regulation stringency (it is equal to μ). Second, if we modify the model by assuming that the government levies a pollution tax on intermediate goods producers, we again find that pollution is not affected by regulation. Thus, we do not find the strong Porter hypothesis when intermediate firms pay the tax. To summarize, regulating the input-emission ratio or taxing intermediate firms lead to qualitatively similar results in the sense that all parts of Proposition 1 except the second are true. Regulators should favor a limit on the amount of pollution as policy instrument.

We also examined the effect of assuming some opportunity cost in R&D when targeting cleaner innovations: $z_t(i) \equiv \frac{1}{A_t(i)^\beta}$, with $\beta \in (0,1)$ ($\frac{\partial \bar{z}}{\partial A}\frac{A}{\bar{z}} = -\beta > -1$). Proposition 1 holds (see Appendix C.4). It also holds if we consider that targeting more ambitious innovation implies an additional R&D cost $c\gamma A_{t-1}(i)$ which we subtract from intermediate profits (Appendix C.5).[10] Another interesting extension relaxes the assumption that a stricter environmental policy does not impact costs of the competitive fringe (Appendix C.6). This assumption is consistent with another assumption of the model that marginal production costs of incumbent intermediate firms are equal to unity and thus do not depend on τ_t either. Instead, one may consider some differentiable function $\chi(\tau_t)$ and examine the direction of the effect of a change in τ_t. There are three cases: (*a*) $\chi' < 0$, (*b*) $\chi' = 0$, (*c*) $\chi' > 0$. Case *b* is that we have considered so far. In cases *a* and *c*, the limit pricing strategy followed by incumbent intermediate firms is not affected because $p_t(i)$ remains equal to $\chi(\tau_t)$ regardless the form of our marginal cost function $\chi(\cdot)$. In case *a* the equilibrium value of x increases because the lower χ has a negative effect on managers' unit rent $\chi - 1$ and on owners' profit $\pi_t(i)$ thus leading managers to increase innovation above γ^{ND}. Case *c* can be interpreted by using symmetric reasoning.

One lesson we draw from these extensions is that the scope of the strong Porter hypothesis is more sensitive to the choice of policy instrument available to the regulator and market configuration than to changes in the specification of the cost functions and the pollution equation.

We conclude this section with some discussion about whether competition policy could interfere with the win-win environmental policy. Let us assume a *decrease* in the cost of imitation χ, which can be interpreted as more potential competition (see Aghion and Griffith, 2005, p. 38). We first show in Appendix C.7 that a decrease in χ has a positive effect on innovation ($\partial\gamma^{ND}/\partial\chi < 0$). The main rationale for this is that a *lower* χ has as direct negative effect on the market power of intermediate incumbent firms whose satisficing managers respond by increasing the size of innovation just enough to avoid bankruptcy. Regarding the combined effect of environmental policy and competition policy on γ^{ND}, it is positive (see Table C.1 in the on-line Appendix on page 22). Table C.2 shows the different values for the pollution variable. A higher tax rate decreases

[10] We could also add a debt repayment obligation to the model, dA_{t-1}, as in Aghion and Griffith (2005). This extension does not change the results. To see this just note that this extension amounts to replace κ with $\kappa + d$ in equation (7).

pollution whereas a lower χ increases it given τ_t. The impact of a stricter environmental policy however is insufficient to offset the detrimental effect of introducing more potential competition. Regarding the response of economic growth to a simultaneous change in τ_t and χ, it is positive, as well as the response of downstream profit (Table C.3).

5. Concluding discussion

This paper extends the Aghion and Griffith's (2005) model with satisficing managers to allow for pollution and environmental taxation. Our theoretical results predict the strong Porter hypothesis that a stricter environmental policy (a higher tax rate in our model) improves growth, the environment, and induces profitable innovations. We checked for robustness of our results to changes in several assumptions and made few extensions. The strong Porter hypothesis holds under some changes in the model specification. However, when innovation is drastic or when a competition policy is undertaken simultaneously with environmental policy we do not find the strong Porter result. In the first case, we find evidence of the weak Porter hypothesis because profit in the downstream sector no longer depends on environmental policy. In the second case, pollution increases. The intuition for this latter result follows from the effect of higher potential competition on the use of inputs. A stricter environmental policy increases inputs quality too little to compensate for the significantly higher use of those inputs. Pollution remains constant in all other cases where Proposition 1 fails. In the following paragraphs we discuss other possible extensions of the model in the direction of addressing whether the assumption of profit maximizing firms is so crucial for the strong Porter hypothesis.

A first extension would be to introduce profit maximizing firms in the intermediate sector. One approach would be to split that sector between a fraction m of inputs produced by profit maximizing managers and the remaining inputs produced by satisficing managers. In doing so one would obtain a one-to-one relationship between the number of firms of a given type and the number of intermediate markets they own. A higher tax rate might adversely affect profit maximizing firms in the short-term. Rebating the fiscal revenue to these firms might solve the problem in the long-term. Instead of extending our model to allow for profit maximizing firms, one could embed environmental policy in the model of Aghion, Dewatripont, and Rey (1999) who consider an economy in which profit-maximizing firms and firms with satisficing managers – who minimize their effort by delaying adoption of more efficient innovations – co-exist. The general equilibrium analysis of their mixed economy, however, is questionable. Equilibrium growth rate in their mixed economy is an *ad hoc* convex combination of growth rates of the two economies (with profit maximizing managers or satisficing managers). Another approach would be to divide the production of each intermediate input between the two types of firms and make some assumption regarding how they compete with each other, as in Aghion, Harris, Howitt, and Vickers (2001), and with the fringe.

A second extension would be to allow for a more realistic agency problem with classical and non-profit maximizing firms. To preserve tractability of the model one could follow Scharfstein (1988). Quality A in non-profit maximizing firms would be affected by the realization of a non-observable random Bernoulli variable. Only managers would observe intermediate output, innovation and the value of the random shock. Intermediate firms' owners would require managers to satisfy a single profit target and condition managers' payment on output.

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Appendix

A Non-drastic innovation

Proof of Proposition 1
(i). *The size of innovation increases with the tax rate* ($\frac{\partial \gamma^{ND}}{\partial \tau_t} > 0$).
Denoting $\frac{1}{1-\alpha}$ by e then equating (9) to zero leads to the following implicit equation

$$h(\tau_t, \gamma) \equiv \gamma - \frac{\kappa}{\chi - 1}\alpha^{-e}\left(\chi + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^e = 0. \tag{A.1}$$

To prove part i we use the implicit function theorem at point (τ_t, γ^{ND}). First, we show that a solution $\gamma^{ND}(\tau_t, i) \equiv \gamma^{ND}$ exists and is unique in a market (note that it differs across markets because of differences in $A_{t-1}(i)$ $\forall i \in [0, 1]$). The function h is continuous and increasing in γ; $\lim_{\gamma \downarrow 0} h(\tau_t, \gamma) = -\infty$ and h is bounded above by B as γ tends to B with $\lim_{\gamma \uparrow B} h(\tau_t, \gamma) = B - \frac{\kappa}{\chi-1}\alpha^{-e}\left(\chi + \frac{\tau_t}{BA_{t-1}(i)}\right)^e < B - \kappa$. We find that $\partial h(\tau_t, \gamma)/\partial\gamma = 1 + e\tau_t/(\chi\gamma A_{t-1}(i) + \tau_t)$ is greater than 1 and therefore invertible; thus, the direction of the effect of an increase in τ_t on γ is given by the sign of $-\partial h(\tau_t, \gamma)/\partial\tau_t = e\gamma/(\chi\gamma A_{t-1}(i) + \tau_t)$, which is positive. Consequently, γ increases as τ_t increases, which proves part i of Proposition 1. Let denote the new solution by $\gamma^{ND'}$ as shown in Figure 1 on page 6). The curve h (the algebraic counterpart of π in the figure) shifts to the right and has a lower slope at the new solution. Combining these results, π lies below the 45° line, as shown in Figure 1, and is concave. We remark that solutions γ^{ND} of (A.1) is greater than 1. Indeed, $h(\tau_t, 1)$ is one minus the product of three terms, each being greater than 1; thus, $h(\tau_t, 1)$ is less than 0. But, h is increasing in γ. Consequently, $\gamma^{ND} > 1$ and so is $\gamma^{ND'}$.

‖

(ii). *Pollution decreases as the environmental tax rate increases* ($\frac{\partial P_t}{\partial \tau_t} < 0$).
Using our definition for e, pollution in any intermediate market (see equation 6) can be written as $\alpha^e\left(\chi + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^{-e}$. Its derivative at point (τ_t, γ^{ND}) has the same sign as

$$-\frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right) = -\frac{1}{\gamma^{ND}}\left(1 - \frac{e\tau_t}{\chi\gamma^{ND}A_{t-1}(i) + \tau_t + e\tau_t}\right) < 0.$$

‖

(iii). *The growth rate of the economy* $(y_t - y_{t-1})/y_{t-1} \equiv g$ *is positive; it increases with* τ_t.
To ease the exposition we remove the exponent 'ND'. From the zero-profit condition, $x_t(i) = \frac{K}{\chi-1}A_{t-1}(i)$ and $x_{t-1}(i) = \frac{K}{\chi-1}\frac{A_{t-1}(i)}{\gamma(i)}$. Using these results and denoting $\Gamma(i) \equiv \gamma^{-\alpha}(i)A_{t-1}(i)$ and $s(i) \equiv \frac{\Gamma(i)}{\int \Gamma(i)di}$, we can show $\frac{y_t}{y_{t-1}} = \int s(i)\gamma(i)di$, which is a convex combination of the $\gamma(i)$'s. But, $\gamma(i) > 1$ (see the proof of part i of the Proposition). Thus, $\frac{y_t}{y_{t-1}}$, which is a convex combination of the $\gamma(i)$'s, all greater than 1, is greater than 1, which proves that $g > 0$. Using the Leibniz's rule, g_{τ_t} is equal to

$$\int s\left(\alpha\gamma\frac{\int(\gamma_{\tau_t}/\gamma)\Gamma}{\int\Gamma} + (1-\alpha)\gamma_{\tau_t}\right)di,$$

which is the integral of s times a convex combination of positive terms. It is positive, thus proving the third part of Proposition 1. ‖

(iv). A higher tax rate increases downstream firms' profit $(\partial\pi_t(y)/\partial\tau_t > 0)$.
Using equations (2), (4) and the assumption $p_t(i) = \chi$, downstream profit can be rewritten as:

$$\pi_t(y) = \int_0^1 \left(\frac{1-\alpha}{\alpha}\right)(\chi + \tau_t/A_t(i))x_t(i)di. \tag{A.2}$$

Replacing $x_t(i)$ with the right hand side of (5), using (8) as well as the implicit profit equation, one obtains the following reduced downstream profit equation:

$$\pi_t(y) = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\kappa}{\chi-1}\right)\int_0^1 \left(\chi + \frac{\tau_t}{\gamma^{ND}(\tau_t,i)A_{t-1}(i)}\right)A_{t-1}(i)di. \tag{A.3}$$

To prove part *iv* of Proposition 1, we differentiate equation (A.3) with respect to τ_t at point $(\tau_t, \gamma^{ND}(\tau_t, i))$. But, $\frac{\partial}{\partial\tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right) > 0$ as shown in part *ii*. Therefore, $\frac{\partial\pi_t(y)}{\partial\tau_t} = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\kappa}{\chi-1}\right)\int\frac{\partial}{\partial\tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right)$ is positive, which proves part *iv* of the proposition. $\|$

B Drastic innovation

Assuming innovation is drastic changes the direction of the inequality $\alpha^{-1} > \chi$ to $\alpha^{-1} < \chi$. Remember that α^{-1} is the monopoly price intermediate firms would charge were regulation absent (see footnote 6 on page 4). Under regulation, this price is higher than α^{-1} to reflect the tax on pollution in the downstream sector. Assuming that in its intermediate input market i incumbent maximizes $(p_t(i) - 1)x_t(i)$ with respect to $x_t(i)$, where the final sector's inverse demand is given by equation (4), we obtain the following quantity $x_t^D(i) = \alpha^{\frac{2}{1-\alpha}}(1 + \tau_t/A_t(i))^{\frac{1}{\alpha-1}}A_t(i)$, where 'D' stands for drastic, and corresponding monopoly price $p_t^D(i) = \alpha^{-1} + \alpha^{-1}(1-\alpha)\tau_t/A_t(i)$. We add two new assumptions, which are $\alpha^2 > 1/\chi$ and $\tau_t < \alpha A_{t-1}(i)\ \forall i$. These assumptions are sufficient conditions for $\alpha^{-1} < p_t^D(i) < \chi$. The first assumption implies that of a drastic innovation $(\alpha^2 > 1/\chi \Rightarrow \alpha^{-1} < \chi)$. The second assumption sets an upper bound for the value of the tax rate.

The size of innovation γ^D is determined by satisficing managers, $\gamma^D : (p_t^D(i)-1)x_t^D(i) - \kappa A_{t-1}(i) = 0$ as in the case of non-drastic innovation with the difference that the economic rent per unit of x, $p^D - 1$ is endogenous. The implicit equation can be rewritten

$$\gamma - e\kappa\alpha^{-(1+\alpha)e}\left(1 + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^{e\alpha} = 0, \tag{B.1}$$

where e was already defined. To prove that the size of innovation increases with τ_t, we follow the same steps as in the proof of Appendix A. We rewrite the function at the left hand side of (B.1) as $h^D(\tau_t, \gamma)$. It is increasing in γ. Using the assumptions $\alpha^{-1} < \chi$ and $\kappa > \chi - 1$ in (B.1) we can show that $\gamma^D > 1$. Then we find $\partial\gamma^D/\partial\tau_t = \frac{e\alpha\gamma^D}{\gamma^D A_{t-1}(i) + \tau_t + e\alpha\tau_t} > 0$, using the implicit function theorem. Regarding the effect of a more stringent policy on pollution, note first that

$$P_t^D(i) = x_t^D(i)/A_t^D(i) = \alpha^{2e}\left(\frac{1}{1 + \tau_t/\gamma^D A_{t-1}(i)}\right)^e. \tag{B.2}$$

Differentiating (B.2) with respect to τ_t leads to a decrease in pollution; the proof follows that of the second part of Proposition 1 in Appendix A. The derivative of $P_t^D(i)$ at point

$(\tau_t, \gamma^D(\tau_t))$ has the same sign as

$$-\frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^D}\right) = -\frac{1}{\gamma^D}\left(1 - \frac{e\alpha\tau_t}{\gamma^D A_{t-1}(i) + \tau_t + e\alpha\tau_t}\right) < 0.$$

The growth rate of the economy increases as τ_t increases when innovation is drastic. The proof is simpler than that when innovation is non-drastic, for it is easier to see that the ratio of outputs

$$\frac{y_t}{y_{t-1}} = \frac{\int_0^1 A_{t-1}(i)di}{\int_0^1 (\gamma^D(i))^{-1} A_{t-1}(i)di},$$

is greater than 1 and increases with τ_t. However, downstream profit, $\pi_t(y) = \frac{\kappa}{\alpha}\int_0^1 A_{t-1}(i)$, does not depend on τ_t; thus, the downstream sector can not benefit from the positive effect that environmental policy has on size of innovation. Considered together, these results verify the weak Porter hypothesis, which we defined in the introduction of the paper.